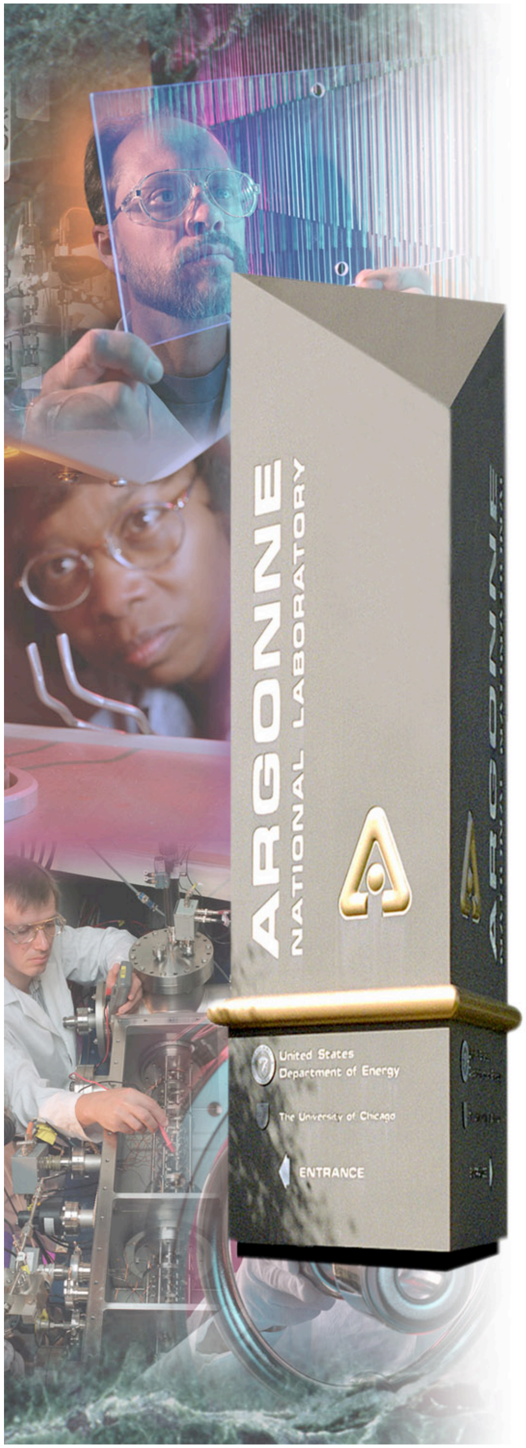


Ultrafast and ultrasmall:

focusing on atoms

Linda Young
Wksp on Ultrafast X-ray Science 2004
Apr 28-May 1,2004

Argonne National Laboratory

Office of Science
U.S. Department of Energy
A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

Collaborators

Atomic Physics Group

Bob Dunford, Dave Ederer, Elliot Kanter,
Bertold Krässig, Steve Southworth, Linda Young

X-ray Optics : *Eric Dufresne (MHATT-CAT)*

Ultrafast Laser: *David Reis, Matt DeCamp (U Michigan)*
Eric Landahl (MHATT-CAT, APS)
Rob Crowell, Dave Gosztola (ANL)

Outline

- ***Motivation***
- ***Background***

  - threshold shift for valence photoionization
- ***First experiment***

  - theshold shift for inner shell photoionization

  - technical challenges

  - experimental strategies

  - results so far
- ***Summary and outlook***

X-ray facilities: toward ultrafast & ultraintense

Single bunch specs

Advanced Photon Source

10^8 x-rays 87 ps

SPPS
Sub-Picosecond Photon Source

$\approx 10^7$ x-rays 80 fs

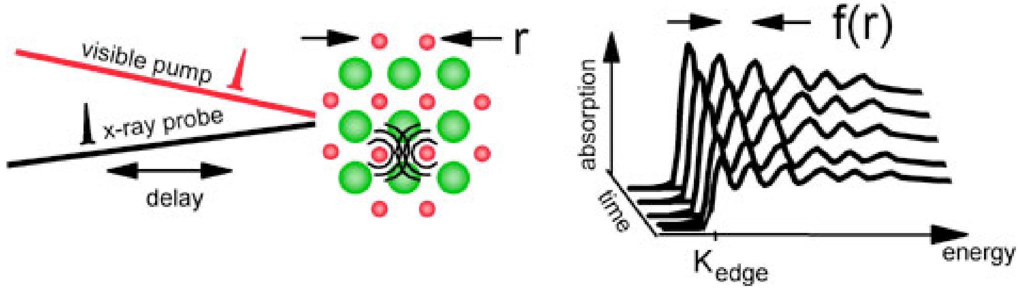
15 GeV Electrons LCLS 1.5 Å X-Ray
Linac Coherent Light Source

10^{12} x-rays 230 fs

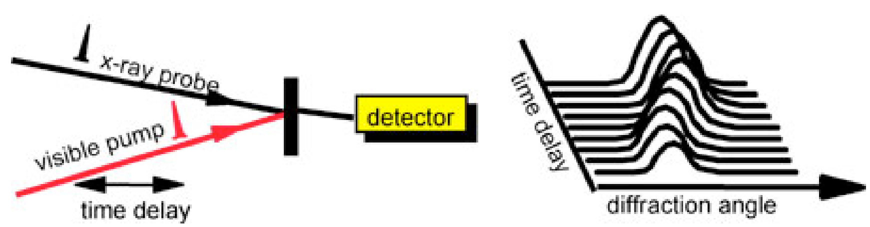
Ultrafast x-ray science

LUX website

Time-resolved EXAFS, NEXAFS, surface EXAFS



Time-resolved x-ray diffraction



Laser-pump/x-ray probe techniques central
Short pulses automatically yield high intensities
1 mJ/100 fs/(0.1 mm)^2 ≈ 10^{14} W/cm^2 ≈ 3 V/Å

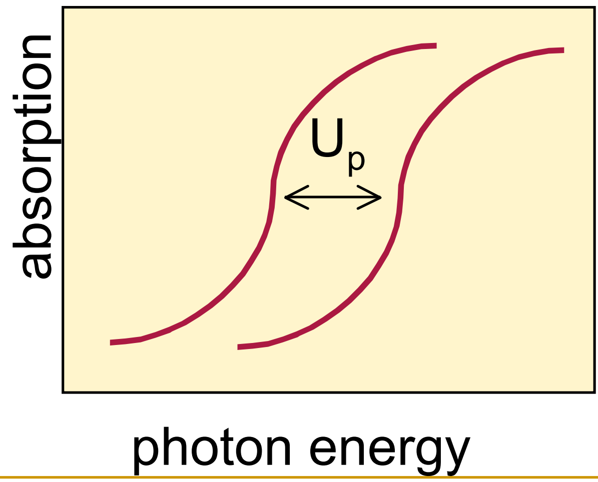
Ultrafast laser/x-ray interactions: isolated atoms

- ***X-ray photoionization is fairly well understood in the weak-field limit***
- ***Understand changes to x-ray processes in presence of strong laser fields***
- ***Theoretical predictions***

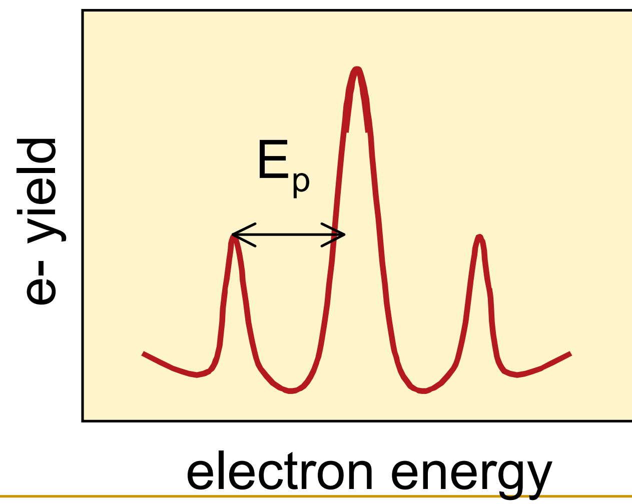
  ponderomotive shift in threshold -> absorption spectrum

  free-free transitions in continuum -> electron spectra

Ponderomotive shift



Electron satellites



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Ponderomotive Shift: photodetachment in Cl^-

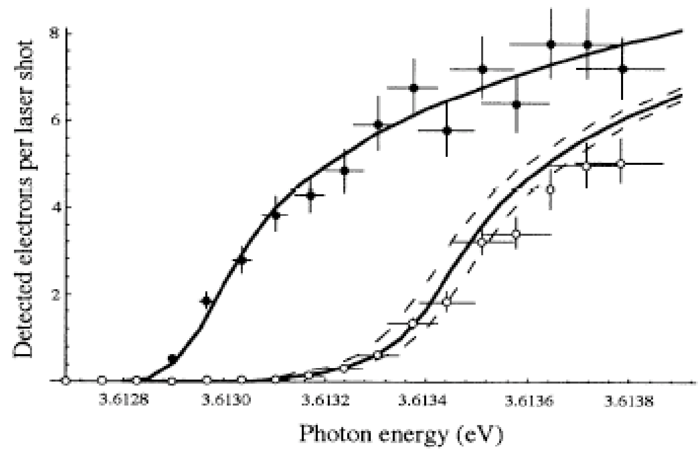
Shift threshold by U_p: $U_p = e^2E^2/4m\square^2$

$U_p \approx (9.33 \times 10^{-14} eV)\ I(W/cm^2)\ \square^2(\square m)^2$

M.D. Davidson, J. Wals, H.G. Muller, H.B. van Linden van den Heuvell
PRL 71, 2192 (1993)

IR: 15 mJ, 13 ns, 146 µm
I_{1064} = 4.5 x 10^9 W/cm^2
U_p = 0.00045 eV

UV: 14µJ, 3.4 ns, 36 µm



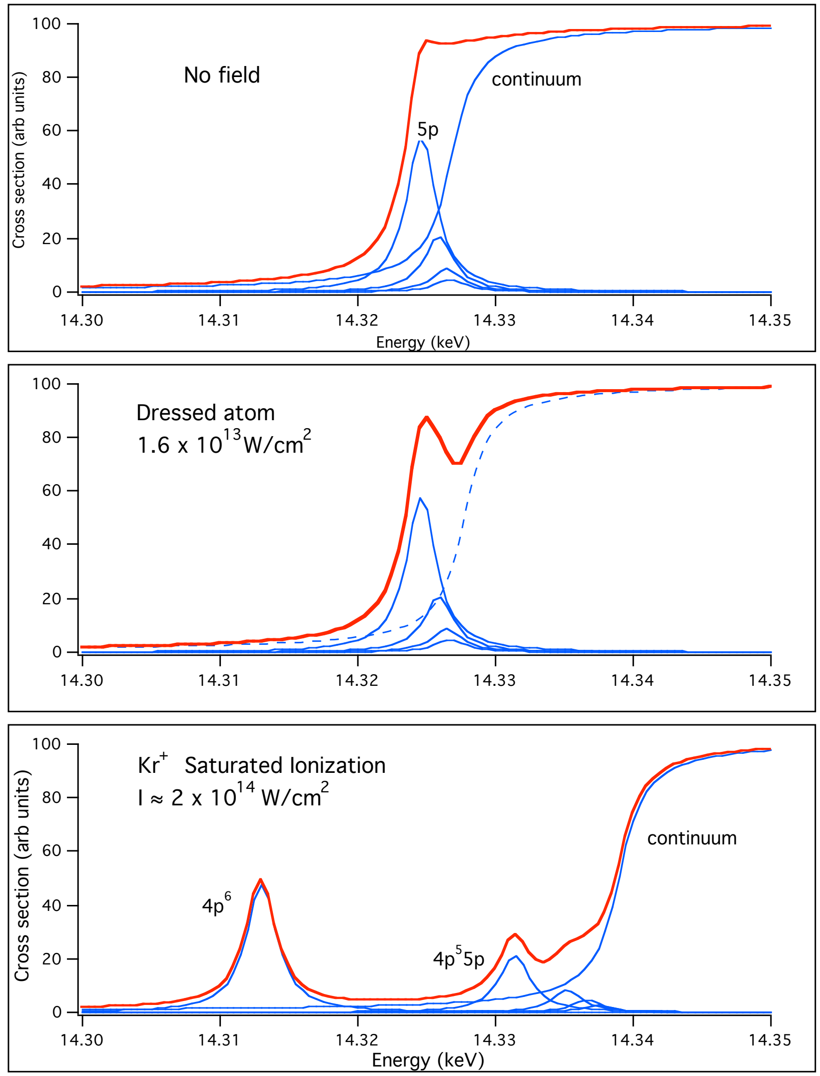
Overlap is critical !!
Well-defined optical field □ dressing beam □ >> probe □
10^{14} W/cm^2 @ 800 nm □ U_p = 6 eV

Evolution of Kr 1s-edge structure

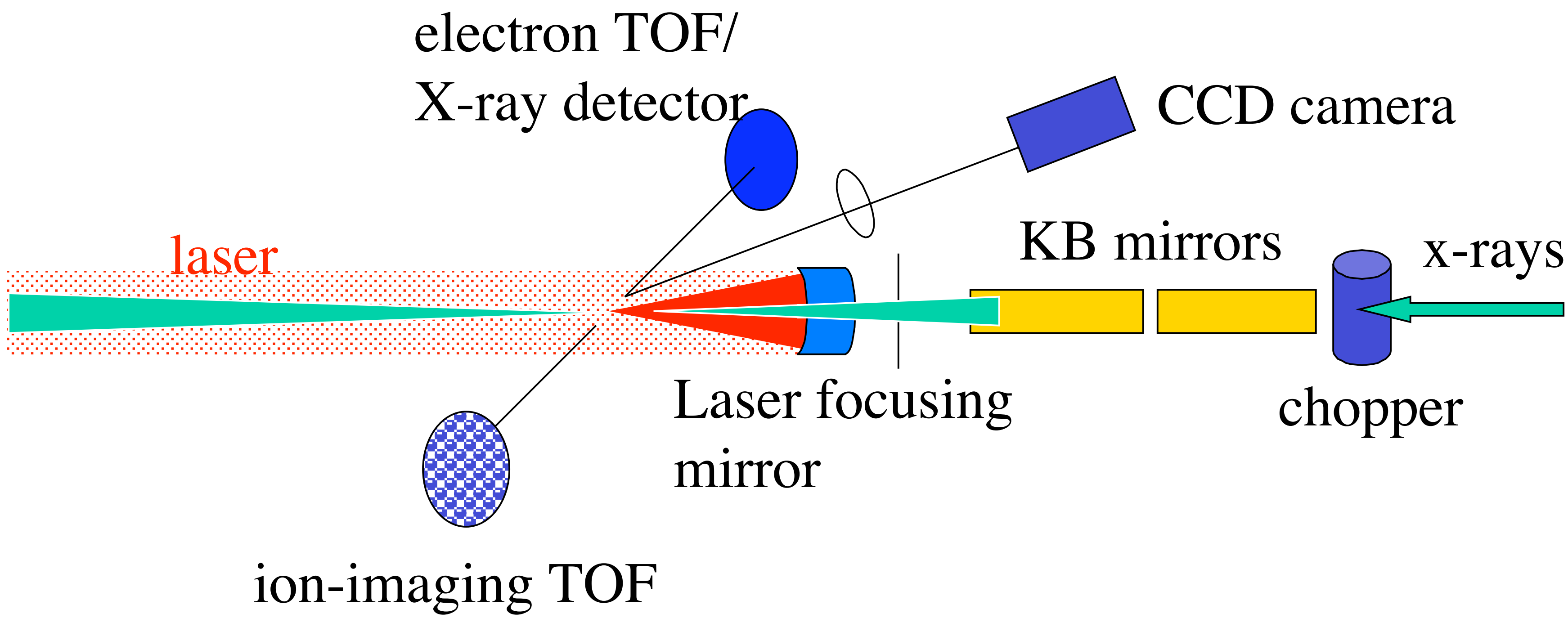
- *Naked atom: I=0*
- *Dressed atom: $I<I_{sat}$*
- *Ion spectrum: $I>I_{sat}$*

For Kr: 800 nm

$I_{sat} \approx 2 \times 10^{14}$ W/cm^2



X-ray processes in presence of strong fields



Technical Challenges

- *Laser intensity*

  MHATT-CAT Ti:sapphire laser

  ≈800±10 nm, ≈100 fs, ≈1 mJ/pulse

  To achieve 10^{14} W/cm^2

  Short pulse (100 fs) focus to ≈100 µm

  Long pulse (100 ps) focus to ≈3 µm

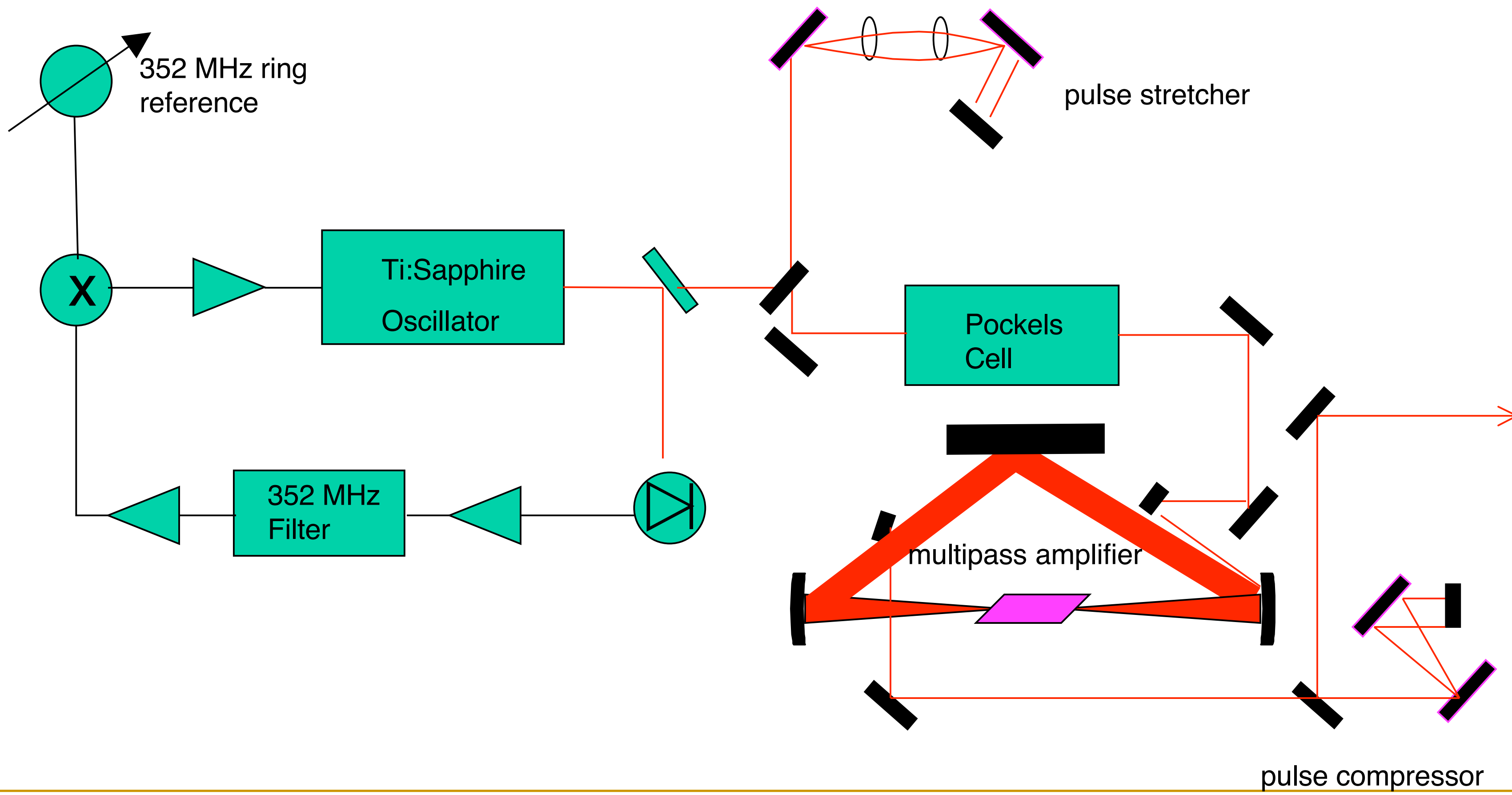
- *Overlap - spatial and temporal*

  X-rays: 87 ps, 2 x 3 µm

- *Count rates*

MHATT-CAT Ti:Sapphire Laser System

Oscillator: 88 MHz, 1nJ, 50 fs
Amplifier: 1 kHz, 1mJ, 50 fs



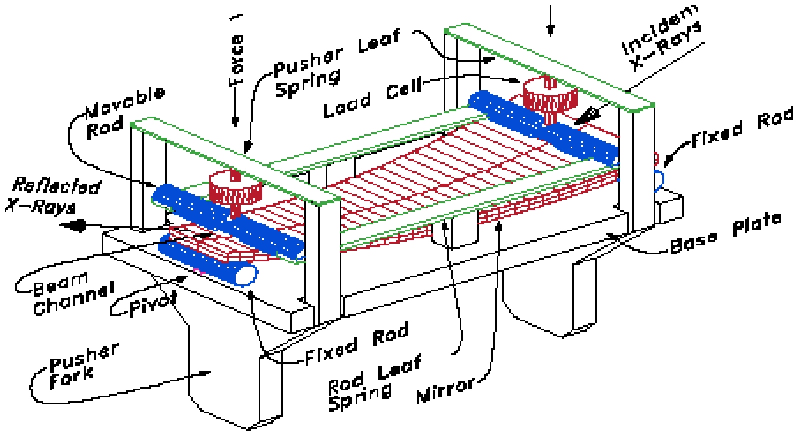
Focus x rays with Kirkpatrick-Baez mirror pair

- *four point bender and trapezoidal mirror substrate is used to create an elliptical shape*

- *a pair is used for vertical and horizontal focusing*

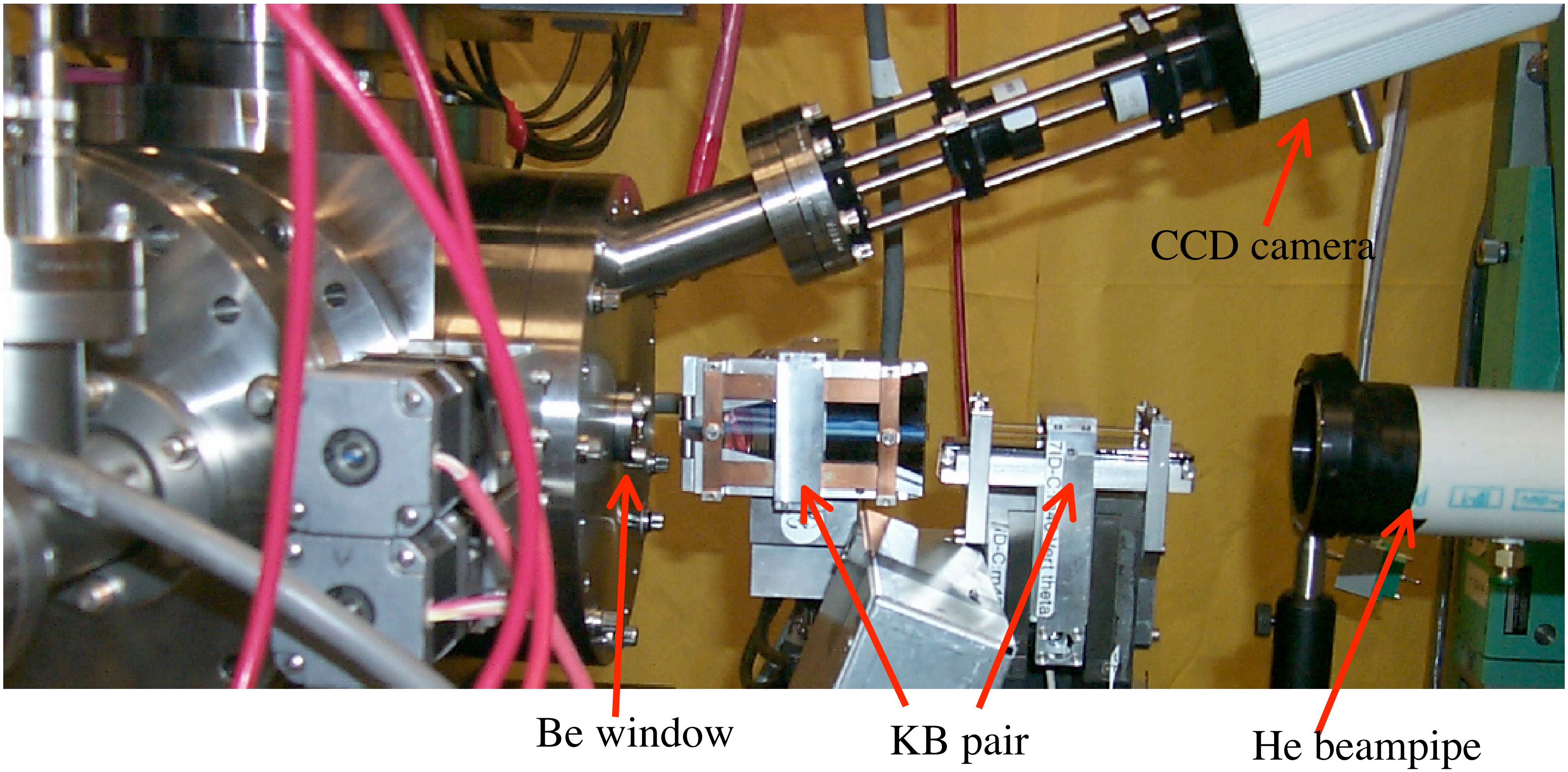
- *focused spot size of ≈1 x 1µm is possible with short working distances*

- *"optimal" spot size 2 x 3 µm calculated for our working distance*



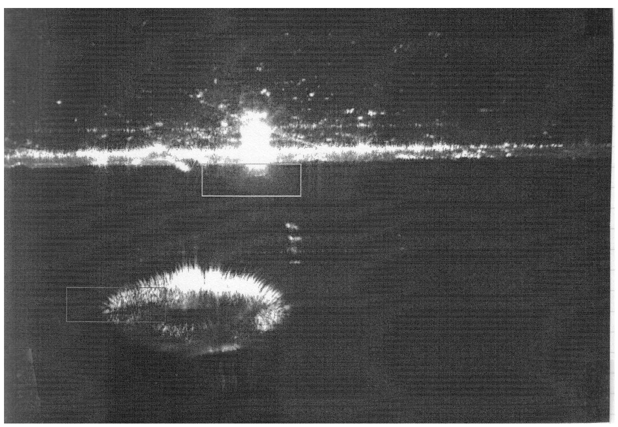
Design by Peter Eng GeoCARS, U Chicago

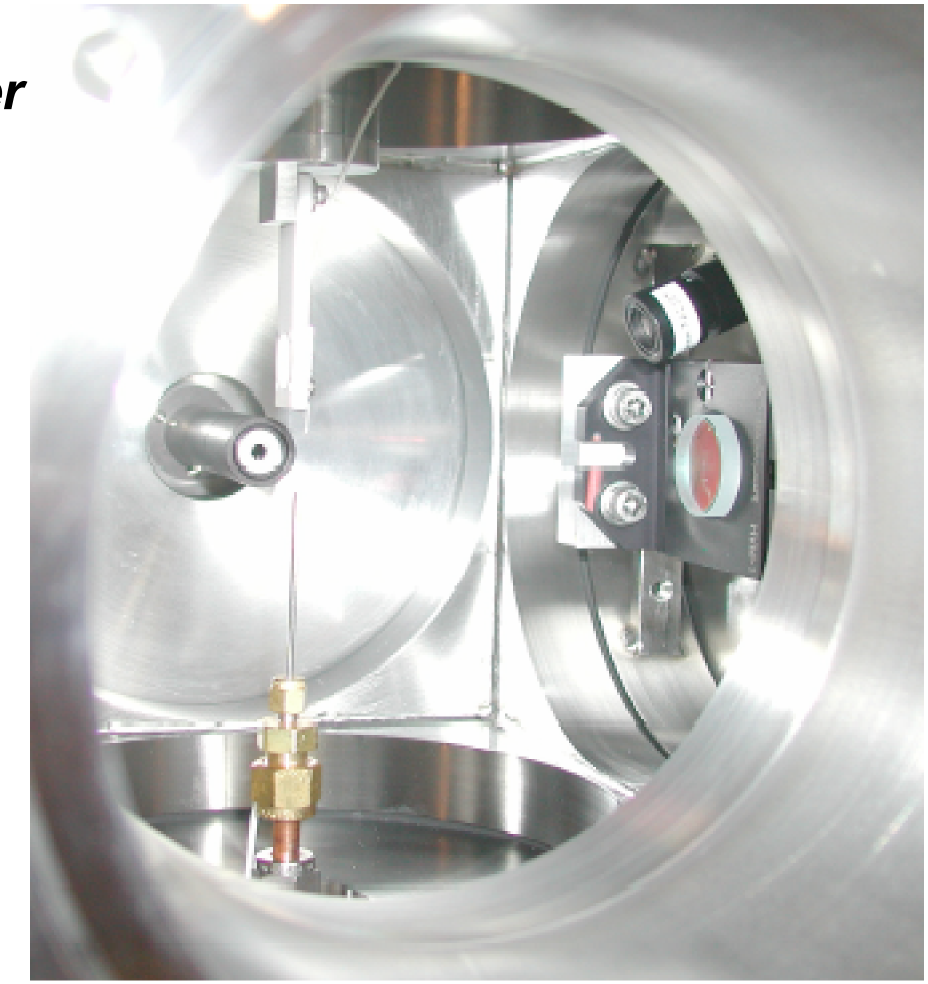
KBs in action



Alignment Strategy

- ***Focus x rays to center of chamber***
- ***Locate x-ray centroid with BGO***
- ***Overlap focused laser***
  - -rough: BGO crystal
  - -fine: in-vacuum cross hairs



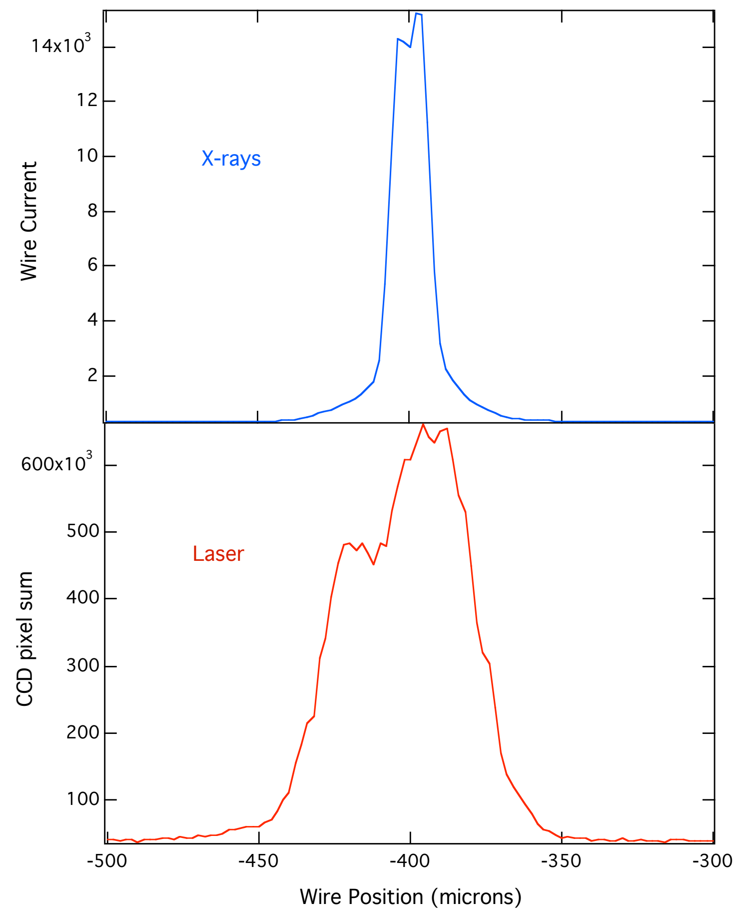


Simultaneous overlap of laser & x-rays

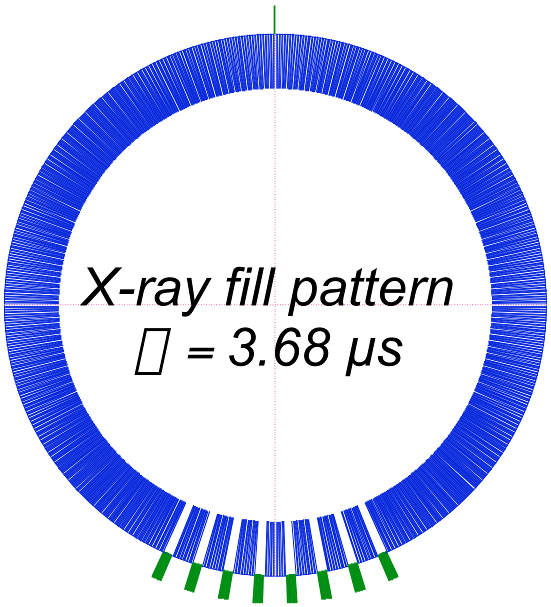
Scan 10 µm cross-hair

X-rays: monitor current
from electrically isolated cross-hair

Laser: monitor scattered light
pixel sum from a selected region on CCD camera

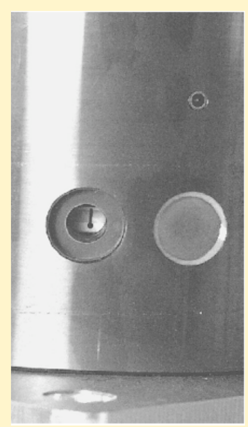


X-ray flux coincident with 1 kHz laser



Only 1/5440 of x-ray flux is coincident with laser (overlap with singlet (1/20 total flux) @ 272 kHz)

Chopper selects singlet x-ray pulses @ 2.66 kHz
Laser @ 887 Hz : 1 laser-on vs 2 laser-off



0.51 mm slot
50.8 mm diameter
2.45µs open time

Count rates in Kr atomic beam

Monochromatic x-rays @ 14.3 keV:
≈ 10^{13}/s ($2\text{x}10^{6}$/pulse)

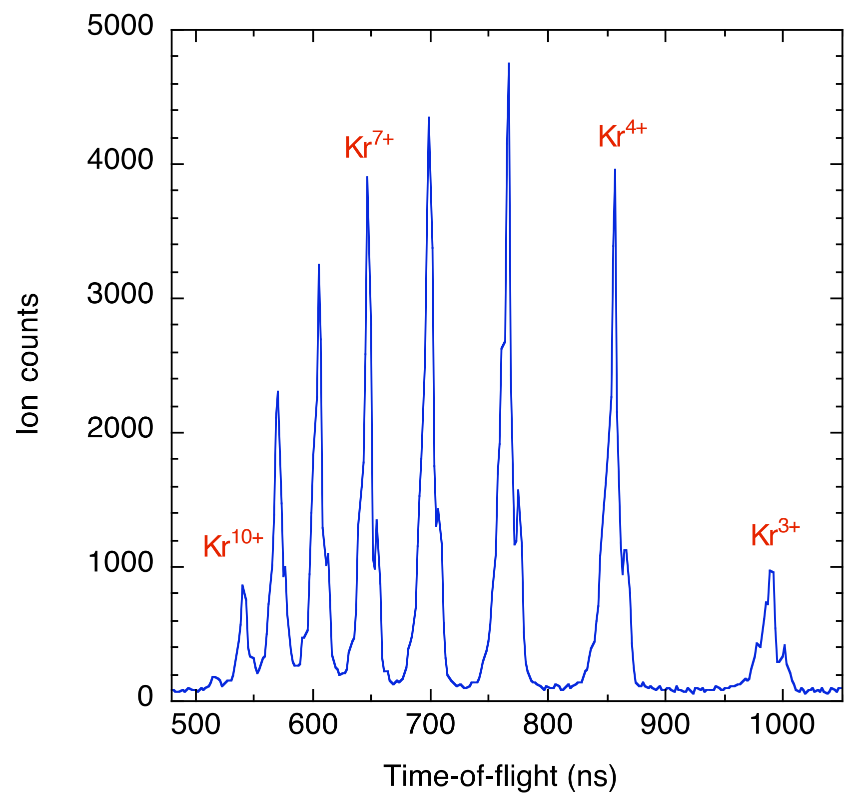
Focused x-rays ≈ 10^{12}/s

Laser frequency ≈ 887 Hz

$I_{x\text{-}ray}$(laser-on) ≈ 2 x 10^{8}/s

σ = 18 kb, n ≈ 10^{12} cm^{-3}, L ≈ 0.3cm

Rate ≈ I σnL ≈ 1 Hz



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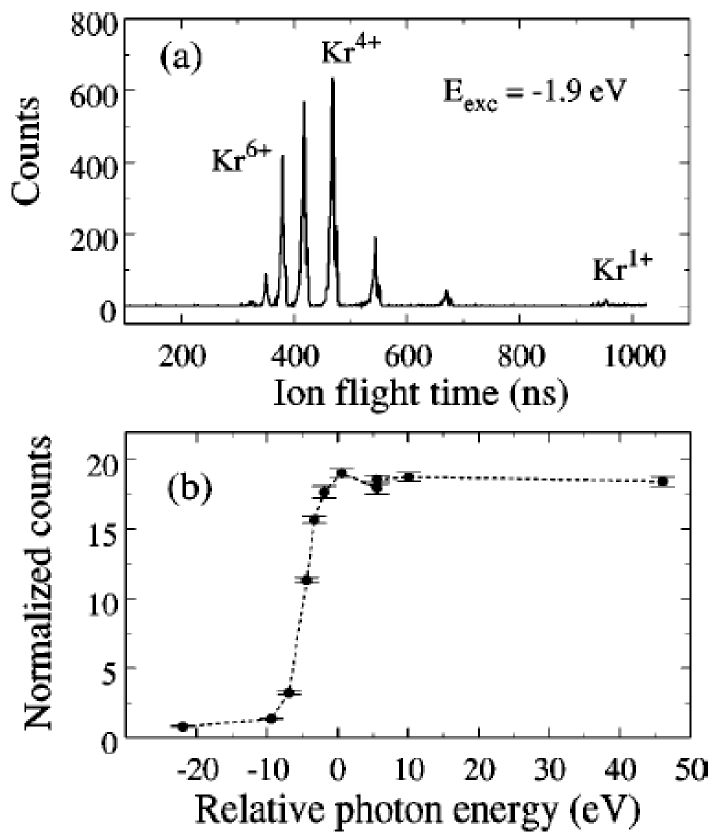
Measurement of Kr 1s Near Edge Spectrum

- *Ion or x-ray yield to measure absorption spectrum*
- *Measure threshold structure point by point*
- *Cross-correlation: laser + x-rays via ion charge state spectroscopy*



Spectrum: 50 points x 10 min/point
500 minutes

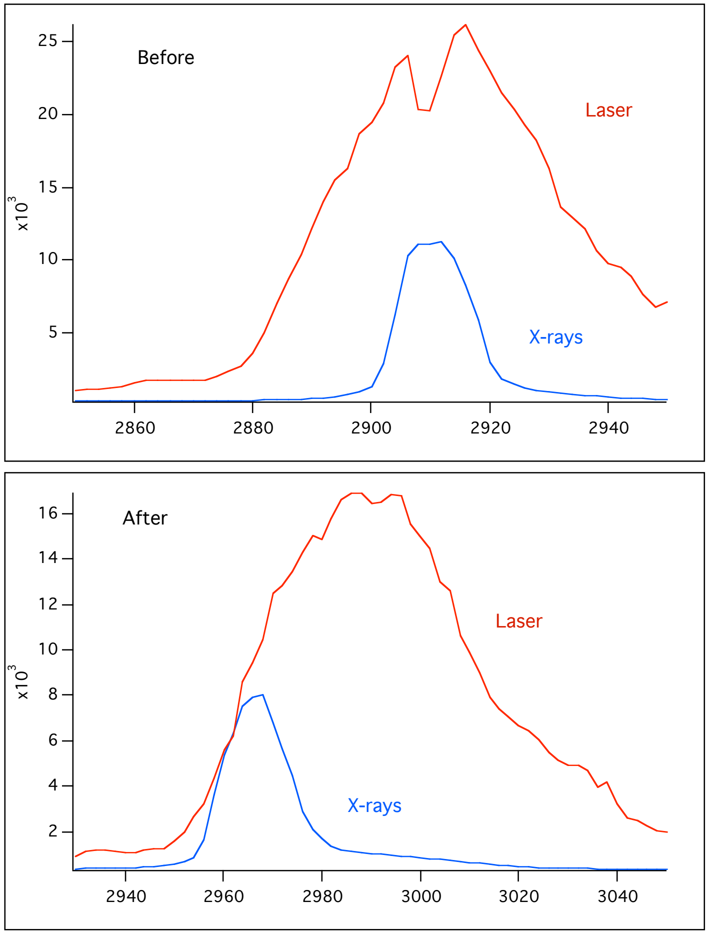
"Stability" of laser/x-ray overlap

Spatial overlap drifts ≈30 microns/4 hrs

Beam position stabilization required

Temporal overlap was stable

Vertical Wire Scan



Summary and outlook

- ***Goal: Understand changes to x-ray processes in presence of strong-laser fields***
- ***Technical issues solved***
  - ***Overlap***
  - ***Dressing intensity (in short pulse mode)***
  - ***Count rate***
  - ***Stability of overlap***
- ***Unique capabilities and personnel associated with APS Sector 7***
- ***Next run June 2004***